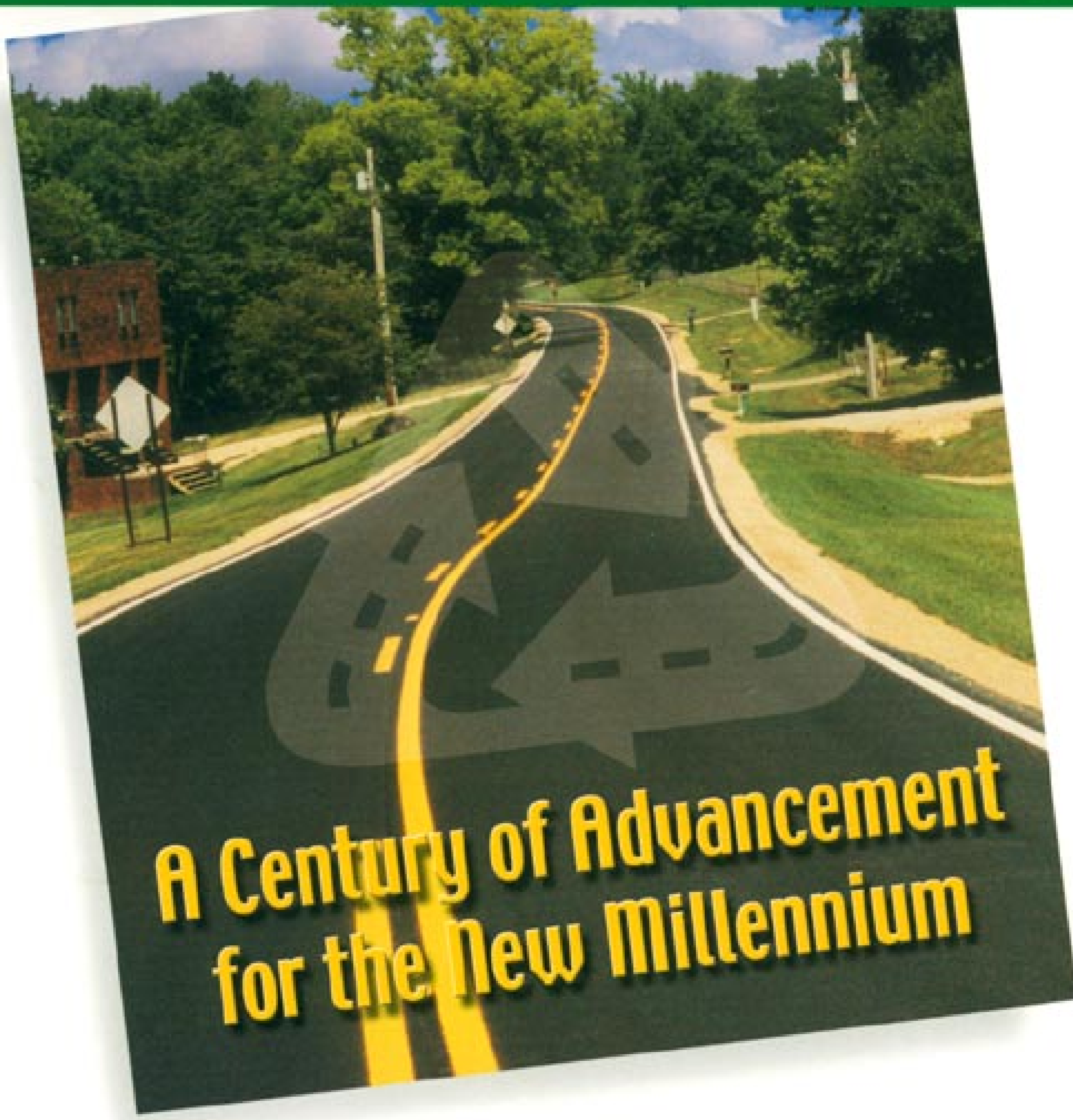
FULL DEPTH RECLAMATION



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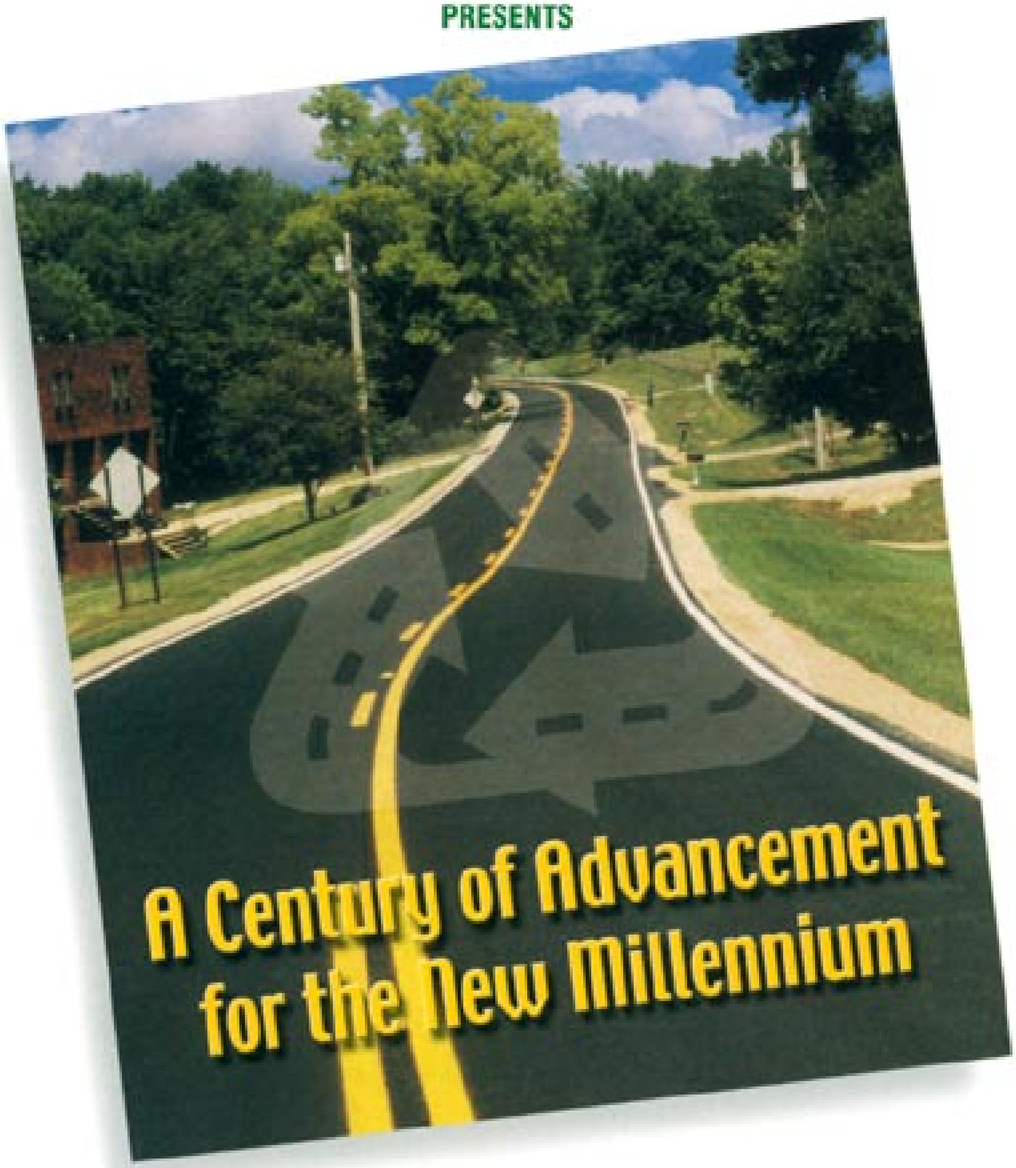

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PREFACE

This publication provides a reference on the state of the practice in Full Depth Reclamation as it is used on various projects such as roadways, parking lots and airfield rehabilitation.

The publication is not meant to be an exhaustive treatise on all aspects of Full Depth Reclamation. It should be supplemented with other authoritative sources such as ASTM and FHWA references, AASHTO references and specifications, and specifications and procedures from various federal and state agencies as well as non-governmental agencies which utilize Full Depth Reclamation. Another source with a wealth of information to offer is the Asphalt Recycling & Reclaiming Association, along with its many Contractor, Supplier and Affiliate members who continue to perfect the many innovative rehabilitation processes available to specifying agencies around the world.

This publication is designed to provide a comprehensive though not exhaustive overview of Full Depth Reclamation (1) processes (2) project evaluation/design (3) additive selection and (4) quality control/quality assurance.

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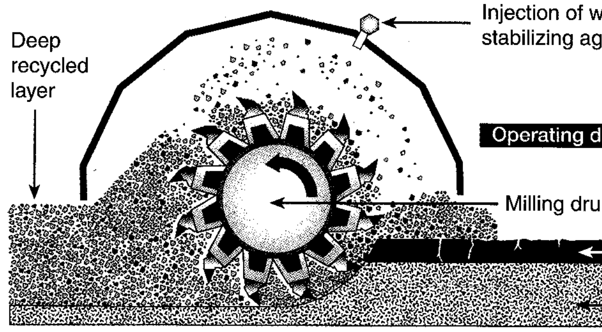
INTRODUCTION

WHAT IS FULL DEPTH RECLAMATION (FDR)?

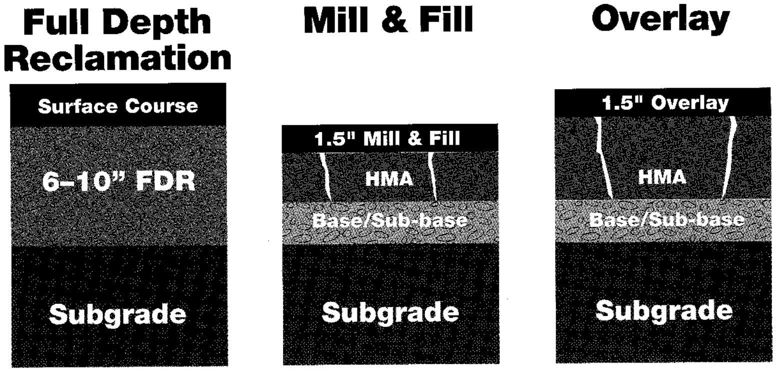
Full Depth Reclamation is a pavement rehabilitation technique in which the full flexible pavement section and a predetermined portion of the underlying materials are uniformly crushed, pulverized or blended, resulting in a stabilized base course; further stabilization may be obtained through the use of available additives. (ARRA)



All pavement structures, with the passage of time and traffic, wear out. In the past it has been convenient to overlay these roadways with additional layers of material, thereby extending their service lives. Eventually, however, due to many factors, these roadways deteriorate to a point that conventional maintenance and/or repair and overlay practices become expensive and do not perform well due to the condition of the underlying structure. It is at this stage in a pavement's lifecycle that costly roadway reconstruction is typically specified. However, due to the evolution of high horsepower road reclaimers with state of the art computerized additive systems, FDR is one of the fastest-growing rehabilitation techniques being specified by pavement engineers around the world. FDR conserves previous investments of in-situ materials while resolving the issues and minimizing the costs of in-situ material disposal common with conventional pavement reconstruction practices. The process has been proven on a wide range of flexible pavement structures to produce quality results at substantially lower costs and considerably shorter construction periods than conventional reconstruction practices.

Full Depth Reclamation is distinguished from other rehabilitation techniques like Cold Planing (CP), Cold In-Place Recycling (CIR) or Hot In-Place Recycling (HIR), by the fact that the rotor or cutting head always penetrates completely through the asphalt section into the underlying base layers, thereby erasing deep pavement crack patterns and eliminating the potential of reflective cracking. With today's innovative equipment and vast range of stabilizing additives, FDR can be utilized to depths exceeding 12", although it is typically performed at 6" to 9". The pulverized layers and additive(s) become a homogeneous well graded (2"/50mm minus) material with improved structural characteristics.

Full Depth Reclamation provides the ideal opportunity to add stabilizing additives to the new base, either solely or in a variety of combinations, to further enhance the characteristics of the reclaimed material. For example, bituminous stabilizing agents, in the form of asphalt emulsion or foamed asphalt, may be added to achieve a flexible bound material with high fatigue resistance. For added compressive strength, Portland cement or fly ash is sometimes blended with the new base. In areas where the freeze/thaw cycle is severe, liquid calcium chloride is often added to the new base. To reduce plasticity and improve load-bearing characteristics, the addition of lime may be specified. If necessary, additional granular material can also be added for improving gradation and/or lessening the asphaltic binder content, thereby increasing the structural characteristics of the base.

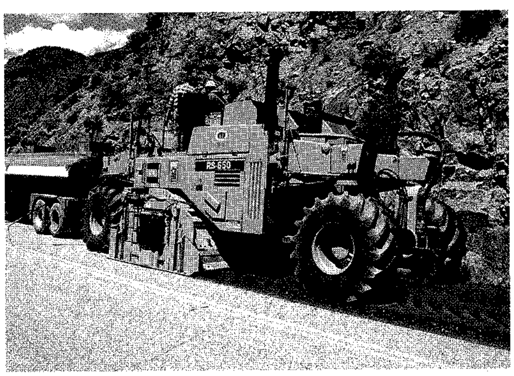


As shown in this graphic, Full Depth Reclamation is the only rehabilitation technique that completely eliminates an existing crack pattern, therefore significantly lowering the pavements' future preventative/corrective maintenance costs.

This fact, when considered in the life cycle cost analysis of a pavement, is why Full Depth Reclamation is the most cost-effective road rehabilitation technique available.

There is much versatility in the process with regard to the types of flexible pavement structures that are appropriate for Full Depth Reclamation. Much of the early reclamation work was done on low volume, secondary roads. Typically these roads evolved from dirt roads to gravel roads to oiled surfaces to chip and seal surfaces. These roads are often narrow, parabolic in shape, and really not designed to support increased traffic volumes and weight. Many are ideal candidates for FDR and benefit from the base strengthening and, sometimes more importantly, widening that can easily be done during the process.

City streets and medium volume roadways are reclaimed more often today, mostly due to advances in the design and horsepower of the reclaimers performing the work and the innovative use of specially designed stabilizers. Where frequent cracking, potholes, and patching are present, FDR is a very viable and longer lasting alternative to an overlay or cold planing and overlay (mill and fill). With adequate project management, traffic can be maintained – a fact that is appreciated by the traveling public and nearby business and homeowners. Another notable point is that due to the improved structural characteristics of the base, a double chip and seal or cape seal may suffice as the surface treatment on low to medium volume roadways, thereby saving money on expensive imported materials and their costly placement.



Reclaiming machines have even been hard at work on Interstate highways and private and regional airports. Rather than paving directly over cracked or distressed asphalt, the new base or surface asphalt overlay goes on top of a stabilized uniformly compacted base. In some cases, the rehabilitation technique also involves the removal of a portion of the asphalt layer, with the remaining asphalt, say 3- 4 inches (75-100mm), being pulverized and blended with the base and applicable stabilizing additives. This is especially useful when curb and gutter reveal or the existing grade needs to be maintained or re-established. With proper design and specifications, the existing pavement distresses are eliminated. This fact, coupled with the contribution of structural integrity provided by a stabilized reclaimed base layer, generally make it possible to decrease the asphalt overlay thickness.

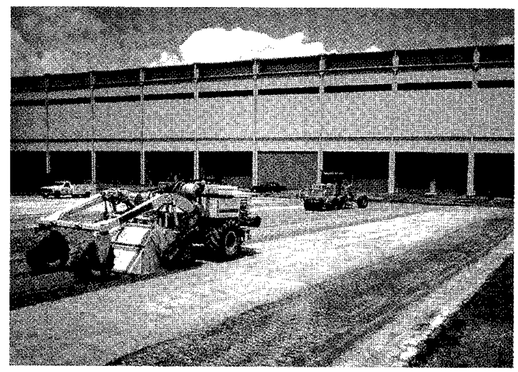
In conclusion, all of the advancements in the equipment and additives involved in the FDR process make it possible to produce deep, strong, and flexible bases capable of withstanding repeated heavy loading in many varying environments. Due to the cost-effectiveness of the process when compared to widespread full depth repairs or total reconstruction, and the savings realized by less expensive surface treatments or thinner asphalt overlays, Full Depth Reclamation is indeed an attractive roadway rehabilitation alternative.

CHAPTER 1

THE FULL DEPTH RECLAMATION PROCESS

Due to the wide array of stabilizers and equipment available for Full Depth Reclamation, the process is generally broken down into four primary disciplines: Pulverization, Mechanical Stabilization, Bituminous Stabilization, and Chemical Stabilization. Although all of these disciplines utilize the same "core" equipment (i.e.–reclaimer, motor grader, compactors and water truck), additional equipment is often required when stabilizing additives come into the picture. Also, the construction sequence often varies when stabilizers are used. Following is an overview of each of the four disciplines, which will hopefully afford a better understanding of how the disciplines compare to each other.

1.1 PULVERIZATION



The first FDR discipline, Pulverization, is the most basic, and therefore most economical FDR discipline available. Because all of the other disciplines share the same basic construction sequence as pulverization, the general construction sequence will be discussed now.

The first step in all of the FDR disciplines includes the pulverization of the in-situ pavement layers and blending of the predetermined underlying material. It is during this step that the specified sizing (gradation curve) shall be accomplished. Sizing is controlled by the reclaimer operator, who balances the machine's forward working speed, cutting rotor speed (rpm), gradation control beam position, and mixing chamber front and rear door position.

Once the material is pulverized, the next step is to add proper moisture to the pulverized material to aid in compaction. Although moisture can be surface added, generally moisture conditioning is best accomplished through the reclaiming machine's integrated fluid injection system during the pulverization step to insure calibrated water consistency throughout the reclaimed material cut depth.

Breakdown compaction takes place immediately behind the reclaimer to achieve a more consistent material density throughout the reclaimed mat prior to any shaping with the motor grader. Compaction equipment used for breakdown rolling range from vibratory pad-foot rollers (52,000-lbs. centrifugal force) to pneumatic rollers (25-ton) relative to the depth and characteristics of the pulverized layer.

Shaping proceeds after breakdown compaction with a motor grader to establish proper grade and cross slope. Top adding water to the surface material is generally necessary as drying may occur from motor grader material manipulation. Intermediate rolling is generally done during this step with a pneumatic roller to knead, or a heavy smooth drum vibratory compactor to seat, any loose aggregates generated by the motor grader. Final or finish rolling can proceed using a 12-14 ton range single or tandem steel drum (static) roller. A fog seal of cut asphalt emulsion or specified sealer is then generally applied to the surface to bond any loose particles and to protect the reclaimed layer from adverse climactic conditions and traffic, prior to the installation of the new surface course.

Due to there being no stabilizing additives added, pulverization is best suited for structures like parking lots, where age and lack of preventive maintenance, not insufficient base thickness, is the reason for failure.

Pulverization is also cost-effectively used on roadways to return the pavement material back to a granular state prior to the addition of a new pavement section

1.2 MECHANICAL STABILIZATION

This discipline of FDR involves the incorporation of imported granular materials during the pulverization or mixing pass of a FDR project. The additional equipment required for this discipline is limited to the dump trucks and stone spreader (if any) required to haul and place the imported granular material. Mechanical stabilization is a cost-effective alternative to simple in-situ pulverization when additional structural strength is needed.

Engineers can specify mechanical stabilization for many reasons, with a few examples being:

- Mechanical stabilization, with proper design practices, will improve the grading of the reclaimed material thus increasing its structural integrity. The decision as to which fraction(s) is to be added is normally based on gradings of samples collected from the in-situ materials.
- Mechanical stabilization can be specified to lean in-situ materials containing high concentrations of bitumen. By incorporating virgin granular material, the excess bitumen has more surface area in which to coat, thereby decreasing the in-place bitumen content and increasing the mixture's structural stability.
- Projected increased pavement elevations can be established and vertical curves can be improved by importing virgin or recyclable granular materials prior to the FDR process.
- Widening can easily be done without sacrificing section thickness.

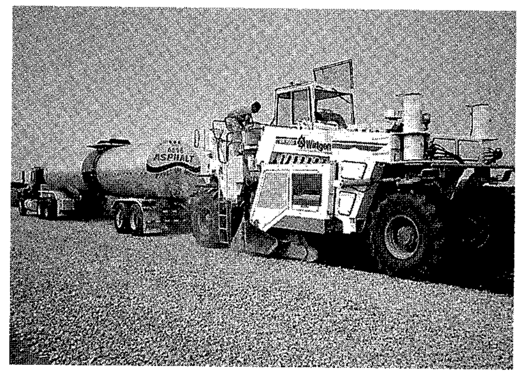
Some of the more common mechanical stabilization additives are crushed aggregates, asphalt grindings (RAP) and crushed concrete (RPC). Mechanical stabilizers can be spread either ahead of the pulverization pass or incorporated into a blending pass after pre-pulverization and shaping. The granular material can be tailgated with end dumps and spread to a uniform thickness with a motor grader, or to achieve a higher level of consistency, it can be placed with various mechanical spreaders or a conventional paver.

Mechanical stabilization is a cost effective FDR process that can be utilized either solely or in combination with other stabilizing additives in the bituminous and chemical families.

1.3 BITUMINOUS STABILIZATION

This discipline of FDR involves the addition of bituminous stabilizing additives. These liquids can be blended into the reclaimed material through the machines integrated liquid additive injection system either during the pulverization pass (single pass) or in a subsequent mixing pass (multiple pass). Consideration is apparent for multiple pass stabilization if there are major surface irregularities and/or distresses in the existing pavement, or if significant changes are required in the final grade and cross slope elevations. With multiple pass stabilization, pulverization at a slightly shallower depth than design specifications and an intermediate shaping step must take place prior to the blending of stabilizing additives. This will insure a more consistent reclaimed layer thickness after placement of material to final grade and cross slope elevations.

Bituminous stabilization has been used in practice for many years. Bituminous stabilization is a cost-effective way of improving the strength of a reclaimed material and reducing the effects of water. Bitumen stabilized materials are more flexible than other base course materials and offer superior fatigue resistance. Also, due to the unique composition of bituminous stabilizers, they work well in combination with other additives such as virgin granular material and/or cement or lime, typically in a slurry state.



Through years of technology, vast ranges of emulsified asphalt products have been developed to enhance the capability of disbursing bitumen homogeneously into moist reclaimed material. Through coring, sampling and laboratory mix design of in-situ material, the proper asphalt emulsion can be selected. Emulsifying asphalt is a highly technical procedure simply defined as a procedure in which tiny bitumen (asphalt cement) droplets, covered with a surface-active agent (emulsifier) to prevent rejoining, are suspended in water. Most asphalt emulsions used in stabilization consist of 60% residual bitumen suspended in the 40% remaining volume of water and emulsifiers. After blending of asphalt emulsions with reclaimed material there is a period of time in which the asphalt emulsion breaks. Break is the point at which the water fraction dissipates, or is lost by some means, and the bitumen droplets rejoin, thereby reverting to a continuous film and coating the reclaimed material particles.

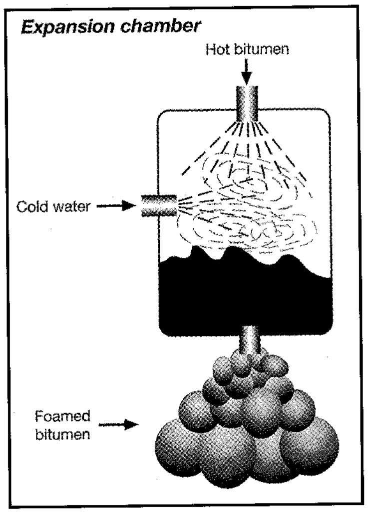
One or more of the following can influence asphalt emulsion break:

- Atmospheric conditions.
- The asphalt emulsions internal chemical composition and characteristics.
- Water evaporation or loss of water through reclaimed material absorption.
- External pressures from mixing and compaction processes.
- Chemical catalysts such as Portland cement or lime.

Emulsion bulk tankers or smaller distributor tankers can be coupled to the reclaimer via a push bar and delivery hose utilizing the reclaiming machine's integrated additive injection system. This is the most effective and consistent method. A second, but not preferred method, is spraying the asphalt emulsion through a calibrated distributor tanker onto the pulverized material and then blending with the reclaimer.

Breakdown compaction should take place immediately after emulsion break and be followed with motor grader shaping. Surface moisture conditioning may be needed if drying is evident along with intermediate rolling with a pneumatic roller. Dependent upon reclaimed layer thickness and curing acceleration, final or finish rolling shall proceed following the establishment of proper grade and cross slope elevations.

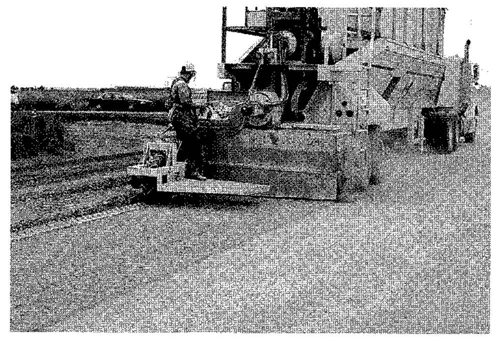
Another technique used today to homogeneously incorporate bitumen into reclaimed material is Foamed/Expanded Asphalt. Asphalt foaming occurs when small amounts of water come in contact with hot asphalt. This thermal reaction increases the surface area of the asphalt, thus decreasing its viscosity. Each tiny foam bubble is a carrier of a thin film of asphalt. Typically 2% by mass of asphalt is the required amount of water to foam standard penetration-grade asphalt. This small amount of water will evaporate off immediately after reaction and not become part of the asphalt. Due to this, an additional amount of water must be added to aid in the compaction of the reclaimed material if in-situ moisture levels are low.



The main advantage of stabilizing with foamed asphalt compared to asphalt emulsions is that there are no manufacturing costs incurred with foam asphalt other than the initial investment of a foaming apparatus. Foam asphalt stabilized material can be placed, shaped, compacted and open to traffic immediately after mixing and remains workable for extended periods of time. Stockpiling and delayed placement is possible requiring only moisture conditioning to aid in compaction. A disadvantage of stabilizing with foamed asphalt compared to asphalt emulsion stabilization is the minimum required 5% fraction of fine material passing 0.075 mm (No.200 sieve). Materials having insufficient fines do not mix well with foamed bitumen. The foamed asphalt does not disburse properly and forms asphalt rich stringers that sit in an unstable state, thereby decreasing the reclaimed base layers strength. When insufficient fines is the case, importing and spreading the missing fraction of fine material is warranted. Unlike asphalt emulsion stabilized material, the larger gradings are not coated with bitumen. The tiny particles of bitumen disbursed by the foam bubbles adhere to the finer gradings producing asphalt-enhanced filler that acts as a mortar or mastic to bind the larger gradings together.

Small amounts of Portland cement or lime can be added to the material to aid in the disbursement of bitumen by increasing the minus 0.075 mm fraction. Also, as with asphalt emulsions, these materials can be added to decrease cure time, improve or eliminate stripping problems, and improve the materials retained strength characteristics.

1.4 CHEMICAL STABILIZATION



This FDR discipline involves the addition of dry or wet chemical additives to stabilize the base material. Chemical stabilization additives such as Portland cement, lime, fly ash, and various blends thereof, are for the most part used as cementitious or pozzalonic additives whereas strength is gained through the cementing of material particles and aggregates in the reclaimed layer. The strength gain is largely governed by the type of reclaimed material being stabilized, along with the type and amount of stabilizers used, as determined through laboratory testing. Too high a percentage can develop strengths that adversely affect the flexibility of the treated material, thereby decreasing the layers' ability to manage repeated loading.

The additives spoken of previously can be applied by spreading ahead of the reclaiming machine in dry powder form with calibrated spreading units, or can be disbursed in slurry form, either on the ground ahead of the reclaimer, or through a suspension material spray bar integrated into the reclaiming machine's mixing chamber.

Chemical stabilization also includes calcium chloride and magnesium chloride, applied dry or in liquid form, resulting in some strength gain through cementing. However, the larger result is the lowering of the reclaimed layer's freezing point, which thereby helps reduce cyclic freeze/thaw in the layer.

It is important to note that the chemical stabilizers and equipment fore mentioned can also be utilized to remedy sub-grade deficiencies noted in pre-project evaluation and design. However, this type of stabilization needs to be considered a separate discipline from the usual FDR disciplines. Incorporation of large amounts of sub-grade soils (more than 50%) into the reclaimed layer structure is not generally considered FDR, but instead sub-grade stabilization.

CHAPTER 2

PRE-PROJECT EVALUATION & DESIGN

As with any rehabilitation project, a thorough pre-project evaluation along with sound engineering practices are the key to successfully achieving the desired end results.

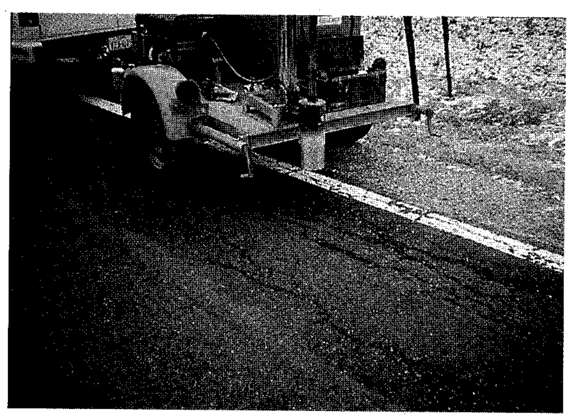
While the type of pavement or structure for which Full Depth Reclamation can be chosen as a rehabilitation technique varies to a high degree, many of the distress signs which indicate a need for the process are the same. These include, but are not limited to:

- Frequent deep cracking (transverse or lateral)
- Reflective cracking (if overlaid)
- Heavy pothole patching
- Severe rutting/shoving
- Frost heaves
- Parabolic shape
- Insufficient base strength

These signs, when coupled with growing traffic (volume and weight) and shrinking budgets, are increasingly leading designers to cost-effective Full Depth Reclamation techniques.

It is important to remember when considering Full Depth Reclamation as an option for rehabilitation, that all distressed areas in the flexible pavement layer are eliminated by pulverization. It is at this point, if proper evaluation and design steps are taken, that substantial stabilization of the in-situ materials can be achieved with available stabilizers.

2.1 PAVEMENT CONDITION AND SAMPLING



The first step in this pre-project evaluation is to perform an existing pavement condition survey in order to determine the type of pave-ment distress and deterioration that has occurred. Once the distresses are identified, the severity of said distresses can be used to verify that Full Depth Reclamation is the proper recycling method based on Table 1 (see next page).

The next step in the evaluation process is to study the in-situ pavement section. The thickness of the asphalt pavement and type and properties of underlying materials must be known. Although a review of previous construction documents or a roadway construction history can provide useful information, core samples or test holes/pits are usually required.

A minimum of two samples per mile is typical with additional locations being selected based upon pavement conditions and variability. This pavement section study, however, should not only focus on the thickness, type and composition of the pavement layers, as it is critical to know the strength and classification of the supporting sub-grade. The in-situ strength or California Bearing Ratio (CBR) of granular bases and sub-grade soils can be easily determined in the field using a dynamic cone penetrometer (DCP) that can be inserted through the core or test holes/pits. If sub-grade samples are required, they can easily be obtained by a push tube or other types of soil sampling equipment. This sub-grade evaluation should not be overlooked since this layer will act as the foundation of the reclaimed base and pavement surface course layers.

TABLE 1 – SELECTION OF IN-PLACE RECYCLING METHOD

Pavement Distress	Hot In-Place Recycling	Cold In-Place Recycling	FDR
Surface Defects			
• Raveling	X1		
• Flushing	X4		
• Slipperiness	X1		
Deformation			
• Corrugations	X4		
• Ruts-shallow 2	X4		
• Rutting Deep 3		X5	X5,6
Cracking (Load Associated)			
• Alligator		X	X
• Longitudinal			
• Wheel Path	X7	X	X
• Pavement Edge		X	X
• Slippage	X8		
Cracking (Non-Load Associated)			
• Block (Shrinkage)		X	X
• Longitudinal (Joint)	X9		
• Transverse (Thermal)		X	X
• Reflection		X	X
Maintenance Patching			
• Spray		X10	X10
• Skin		X10	X10
• Pothole		X	X
• Deep Hot Mix		X	X
Week Base or Subgrade			X
Ride Quality/Roughness			
• General Unevenness	X	X	
• Depressions (Settlement)	X11	X11	X12
• High Spots (Heaving)	X11	X11	X13

1. Applicable if the surface course thickness does not exceed 37 mm (1 1/2 in.).
2. Rutting is limited to the upper portion of the pavement structure top 37-mm to 50 mm (Top 1 1/2 in. to 2 in.).
3. Rutting originating from the lower portion of the pavement (below surface course and includes base and subgrade).
4. May be a temporary correction if entire layer affected is not removed or treated by the addition of special asphalt mixtures.
5. The addition of new aggregate may be required for unstable mixes.
6. The chemical stabilization of the subgrade may be required if the soil is soft, wet.
7. Applicable if the cracking is limited to the surface course of the pavement.
8. Applicable if treatment is to a depth below the layer where the slippage is occurring.
9. Applicable if the cracking is limited to the surface course of the pavement.
10. In some instances, spray and skin patches may be removed by cold planing prior to these treatments (considered if very asphalt rich, bleeding).
11. May be only a temporary correction if the distress is related to a subgrade problem.
12. Used if depressions due to a poor sub-grade condition.
13. Used if high spots caused by frost heave or swelling of an expansive subgrade soil.

2.2 MATERIALS TESTING

The laboratory testing required for FDR varies considerably due to the wide range of pavement materials and stabilizing agents that are involved. For example, the recycled material can consist of nearly 100% reclaimed asphalt pavement (RAP) or may contain appreciable amounts of granular base or soil blended with the RAP.

The following table (Table 2) lists several tests that can be performed on reclaimed mixtures. It is important to note, however, that many of the tests on the asphalt mixture are not conducted unless bituminous stabilization is being considered. Once these tests are performed and the composition of the subject pavement is known, it is time to select an additive and perform the mix design.

TABLE 2 - GENERAL MATERIALS TESTING FOR FDR

DESCRIPTION OF TEST METHOD	ASTM *TEST METHOD
Asphalt Mixtures	
• Quantitative Extraction of Bitumen from Bituminous Paving Mixtures	D2172
• Asphalt Content of Hot Mix Asphalt by Ignition Method	Approval Pending
• Recovery of Asphalt from Solution by Abson Method	D1856
• Penetration of Bituminous Materials	D5
• Viscosity of Asphalts by Vacuum Viscometer	D2171
• Sieve Analysis of Fine and Coarse Aggregates	C136
• Materials Finer than 75p (No. 200) Sieve in Mineral Aggregates by washing	C117
Granular Base and Soil Materials	
• Liquid Limit, Plastic Limit and Plasticity Index of Soil	D4318
• Sand Equivalent Value of Soils and Fine Aggregate	D2419
• Sieve Analysis of Fine and Coarse Aggregates	C136
• Materials Finer than 75 p (No.200) Sieve in Mineral Aggregates by washing	CI 17
• Amount of Material in Soils finer than 75p (No. 200) Sieve	C 1140

**American Society for Testing and Materials*

2.3 ADDITIVE SELECTION/DESIGN

As discussed, FDR may be used for a wide range of pavement applications, e.g. city streets, county roads, interstate highways, airport runways, taxiways and aprons, and at commercial and industrial sites. Where good traffic data is not available for structural design, care must be taken if estimates are used. Selecting the correct type and amount of additive to produce sufficient structural strength in the reclaimed base is equally important.

For selecting the type of additive, reclaimed material characteristics are considered and mixture testing is completed with the appropriate additive based on the properties of reclaimed pavement listed in Table 3 (below). The test procedures in Table 4 (see page 17) are designed to determine the additive amount necessary for achieving adequate structural strength with the in-situ combination of RAP and granular base and/or soils. Material variations, especially in the underlying granular soils, usually necessitate that the structural design be based on the worst case scenario to help prevent pavement failures. For lime, fly ash, cement, and combinations thereof, testing procedures and design parameters are well established. For bituminous stabilization, Hveem, Marshall, and Asphalt Institute mix design methods have been modified for cold mixtures. No standard mix design is presently available for foamed asphalt but procedures similar to those for emulsion are generally being used.

TABLE 3 - GENERAL GUIDELINES FOR SELECTING STABILIZERS FOR FDR - LABORATORY TESTING

Type and Typical Trial Percents of Stabilizer	Characteristics of Reclaimed Pavement Materials
Hydrated Lime or Quicklime 2 to 6% by weight (1)	Reclaimed asphalt pavement (RAP) having some amount of silty clay soil from sub-grade with a plasticity index greater than 10.
Class C Fly Ash (2,3) (8 to 14% by weight)	Materials consisting of 100% RAP or blends of RAP and underlying granular base or soil. The soil fraction can have plasticity or be similar to soils acceptable for lime treatment.
Portland Cement (3) (3 to 6% by weight)	Materials consisting of 100% RAP or blends of RAP and underlying granular base or non-plastic or low plasticity soils. There should be sufficient fines to produce an acceptable aggregate matrix for the cement treated base (CTB) produced (not less than 45% passing the 4.75 mm or No. 4 sieve preferred).
Emulsified or Foamed Asphalt (4) (1 to 3% by weight) (5)	Materials consisting of 100% RAP or blends or RAP and underlying granular base or non-plastic or low plasticity soils. The maximum percent passing the 75 µm (No. 200) sieve should be less than 25%, the plasticity index less than 6 or the sand equivalent 30 or greater, or the product of multiplying the P.I. and the percent passing the 75 µm being less than 72.
Calcium Chloride (1% by weight)	Materials consisting of a blend of RAP and non-plastic base soils with 8 to 12% minus 75 micron material. Small amounts of clay 3 to 5% are also beneficial.

1. Quicklime has been spread dry on the surface of the pavement being full depth reclaimed and water sprayed to slake it (CaO + H20 = Ca(OH)2 + Heat). However, CaO now is being slaked in special mixing tanks and added as a hydrated lime slurry.
2. Class C fly ash is a by-product of the combustion of coal and can be used by itself for stabilization as having cementing properties. Class F ash, however, must be combined with a small amount of an activator (typically hydrated lime or Portland cement).
3. Portland cement has been combined with Class C fly ash in varying ratios for the stabilization of full depth reclaimed materials. Combining of these additives could result in better mixture properties at a lower cost than when either cement or fly ash are only used.
4. Small amounts of hydrated lime or cement, typically 1.5 and 1.0 percent respectively by weight, are being added with asphalt emulsion to produce reclaimed mixtures with higher early strength and greater resistance to water damage.
5. The range in the asphalt content indicated is typical for reclaimed materials containing from 75 to 100 percent RAP by weight. For reclaimed materials with lessor quantities of RAP, some increase in the added Bitumen content probably will be necessary, particularly when having fine graded soil materials (sand or silty sand).

TABLE 4 - TESTING METHODS FOR EVALUATION OF STABILIZED MATERIALS

Type of Stabilizer	Testing Procedures Applicable
Hydrated Lime or Quicklime	Liquid Limit, Plastic Limit and Plasticity Index of Soils, ASTM D 4318 Moisture Density Relations of Soils and Soil-Aggregate Mixtures, ASTM D 698 or D 1557 Unconfined Compressive Strength of Compacted Lime Mixtures. ASTM D 5101, Procedure B
Class C Fly Ash or Cement	Moisture-Density Relations of Soil-Cement Mixtures. ASTM D 558, Method B Compressive Strength of Molded Soil-Cement Cylinders, ASTM D 1633 Wetting and Drying Compacted Soil-Cement Mixtures, ASTM D 559, Test Method B
Asphalt Emulsion or Foamed Asphalt	Modified Hveem Method for Emulsified Asphalt Aggregate Cold Mixture Design, Appendix E, Asphalt Cold Mix Manual" Manual Series No. 14 (MS-14), Asphalt Institute. Percent air Voids in Compacted Dense and Open Bituminous Paving Mixtures ASTM D 3203 Effect of Moisture on Asphalt Concrete Paving Mixtures, ASTM 4867 Indirect Tension Test for Resilient Modulus Bituminous Mixtures, ASTM D 4123
Calcium Chloride	Liquid Limit, Plastic Limit and Plasticity Index of Soils, ASTM D 4318 Moisture Density Relations of Soils and Soil-Aggregate Mixtures, ASTM D 698 or D 1557

ADDITIVE SELECTION GUIDE

Asphalt emulsion is easy to apply and dust-free - it's sprayed into the reclaimer's cutting head where it is mixed with the recycled materials. An emulsion stabilized base is flexible, fatigue resistant, and not prone to cracking. However, it is sometimes more expensive than cement or foamed asphalt and takes time to cure and develop its' full strength. When in-place moisture levels are high, adding emulsion can increase moisture contents to a point above optimum, thereby resulting in an unstable layer.

Cement is easy to apply dry or as a slurry and is sometimes less expensive than emulsion. Dry applications, however, can cause unacceptable dust problems in built up areas. Cement improves resistance to moisture and develops good early strength, but shrinkage cracking can be a problem unless cement content is kept low-usually less than 6%.

Calcium Chloride is a hygroscopic chemical meaning it absorbs moisture. This moisture facilitates compaction and then imparts strength. Calcium Chloride is generally the least expensive of the stabilizers typically used and has been shown to reduce frost heaving. It works best in well graded, non plastic soils containing about 10% minus 75 micron size (-200 mesh) material.

Lime and quicklime are effective economical stabilizers for problematic fine graded soils with Plasticity Indexes (PI's) greater than 10 and minus 75 micron fractions exceeding 25%. As with cement, lime/quicklime application as a slurry makes handling and dust control much simpler.

Foamed asphalt stabilization has recently been reintroduced because of improved and safer state of the art foaming systems that have been developed by various machine manufacturers. Foamed asphalt is usually less expensive than emulsion and does not add water. The base produced has all of the advantages of emulsion stabilized materials, but the strength gain is rapid, thereby allowing immediate traffic. A supply of hot (180^{o} C) asphalt is required and the material being stabilized should have 5-15% passing the 75 micron sieve.

It is important to note when considering these stabilizers that various combinations of them can be used together for various reasons. Fly ash can be used with cement to retard strength gain, thereby decreasing short-term shrinkage cracking. Fly ash can also be used in combination with lime in order to increase the amount of silicates in silicate deficient silty materials which allows for proper pozzalonic strength gain to take place. Various chemical stabilizers such as lime, fly ash and cement, in either dry or slurry form are being used with emulsion and foamed asphalt to produce higher strengths, quicker cure and/or decreased moisture contents (in the case of emulsion), and more resistance to water. Cement is also sometimes used in small percentages with Calcium Chloride if the fines content is higher than recommended, or if additional base strength is required.

2.4 WEATHER LIMITATIONS

The recommended atmospheric temperatures and conditions for completing FDR are controlled by the type of stabilizing additive being used, i.e., asphalt emulsion, foamed asphalt, cement, lime, fly ash or combinations thereof (Table 5). FDR work is not completed if it is raining or rain appears to be imminent. Rain can produce wash-off of asphalt emulsions and pre-mature chemical reaction of dry stabilizers spread on the surface resulting in reduced reclaimed material strength. Also, in the case of asphalt emulsions, work normally does not proceed under foggy or other very high humidity conditions because of poor curing.

TABLE 5 – CLIMATIC LIMITATION FOR STABILIZERS

Type of Stabilizer	Climatic Limitation for Construction
Lime, Fly Ash or Lime-Fly Ash	Do not perform work when reclaimed material can be frozen. Air temperature in the shade should be no less than 4°C (39°F) and rising. Complete stabilization at least one month before the first hard freeze. Two weeks minimum of warm to hot weather is desirable after completing the stabilization work.
Cement or Cement Fly-Ash	Do not perform work when reclaimed material can be frozen. Air temperature in the shade should be no less than 4°C (39°F) and rising. Complete stabilization should be at least one month before the first hard freeze.
Asphalt Emulsion or Foamed Asphalt	Do not perform work when reclaimed material can be frozen. Air temperature in the shade should be no less than 15°C (59°F) and rising. Asphalt emulsion stabilization would not be performed if foggy or when other high humidity condition (humidity >80%). Warm to hot dry weather is preferred for all types of asphalt stabilization involving cold mixtures because improved binder dispersion and curing.
Calcium Chloride	Do not perform work when reclaimed material can be frozen. Air temperature in the shade should be no less than 4°C (39°F) and rising. Complete stabilization should be at least one month before the first hard freeze.

SUMMARY

Full Depth Reclamation is a process whose time has come…
it's environmentally sound, gives enhanced performance, and saves dollars.

Some of its advantages are:

- **Conserves Energy** — it is completed in-place and on grade so trucking and other material handling issues are eliminated or greatly reduced. Also, no heating fuel is needed since it is a cold process.
- **Conserves Materials** — existing pavement materials (stone and asphalt) are re-used, thus conserving limited resources.
- **Crown and cross-slope is easily restored**.
- **Loss of curb reveal can be reduced or eliminated**.
- **Reflective Cracking Eliminated** — existing cracked pavement is completely pulverized.
- **Long Term Cost Effective** — the cause of pavement failure, weak bases, is addressed.
- **Environmentally Desirable** — disposal of old pavement materials is greatly reduced. There is less air pollution due to no heating and/or material hauling.
- **Future Maintenance Costs Are Reduced**.

Full Depth Reclamation techniques allow for minor inconvenience to the traveling public.

ASPHALT
100% RECYCLABLE
"IN-PLACE"

ASPHALT RECYCLING & RECLAIMING ASSOCIATION

The Asphalt Recycling & Reclaiming Association (ARRA) is a non-profit international trade association of contractors, equipment manufacturers, suppliers, public officials and engineers, engaged in the recycling and reclaiming of asphalt—working to build a stronger and safer network of highways, streets, and roads across the country and around the world.

Full Depth Reclamation — A Century of Advancement for the New Millennium, was developed by the Full Depth Reclamation Technical Subcommittee of the Committee on Recycling Education (CORE), and has been based on the collective experience and knowledge of its participating members.

This brochure may be amended from time to time to reflect the latest in state-of-the-art technology.

Additional copies of this and other ARRA publications can be obtained by contacting the Association headquarters, or by visiting us online at: www.arra.org

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